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A FLIGHT INVESTIGATION OF THE EFFECT OF SURFACE ROUGHNESS ON WING PROFILE DRAG WITH TRANSITION FIXED

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ADVANCE RESTRICTED REPORT

A FLIGHT INVESTIGATION OF THE EFFECT OF SURFACE ROUGHNESS ON WING PROFILE DRAG WITH TRANSITION FIXED

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SUMMARY

A flight investigation was made on a wing section of a P-47D airplane to determine the effect of roughness on wing profile drag with transition fixed far forward. Surveys of the wake were made for two surface conditions with transition fixed by a thread at 5 percent chord back of the leading edge on the upper and lower surfaces. One of the surveys was made with the surfaces smooth; the other survey was made with the surfaces roughened by an application of camouflage paint behind the thread. The surface roughness produced by the camouflage paint was made up of particles of about 0.0012 inch in height and numbering roughly 40,000 per square inch.

The results of the investigation indicated that the roughness increased the turbulent skin friction by an amount corresponding to an increase in section profile-drag coefficient of 0.0013, or 16 percent, at a lift coefficient of 0.16 and a Reynolds number of 17×10^6. Below the Mach number at which shock occurred, variations in Mach number of as much as 0.16 appeared to have no appreciable effect on the section profile-drag coefficients of either the smooth or roughened surfaces with transition fixed.

INTRODUCTION

The results of tests reported in references 1 and 2 indicated that roughening the external surfaces of an airplane may cause large increases in drag. In order to provide further information, a brief investigation was made of the effects of surface roughness as one phase of a series of flight tests to determine the profile-drag characteristics of the wing of a P-47D airplane. The tests consisted of surveys of the wake of a wing section, with transition fixed on the upper and lower surfaces by a thread at 5 percent of the chord, for two conditions of the surfaces. One of the surveys was made with the surfaces smooth; the other survey was made with the surfaces roughened by an application of camouflage paint behind the thread. In addition to the effects of roughness, some information on the effects of compressibility on profile drag was obtained.

Measurements were made in level flight and in dives at altitudes of 12,000 and 24,000 feet and over a range of indicated airspeed of from 150 to 360 miles per hour. The lift coefficients obtained in the tests ranged from 0.12 to 0.68, the Reynolds numbers ranged from 8×10^6 to 20×10^6, and the Mach numbers ranged from 0.25 to 0.73.

APPARATUS AND TESTS

The investigation was conducted on a right wing section of a P-47D airplane (figs. 1 and 2). This wing section, a Republic S-3 section, had a chord of 86.05 inches, a thickness of 11 percent of the chord, and was located at 63 percent of the semispan from the plane of symmetry or about 2 feet outboard of the flap. At this spanwise station the test section was outboard of the propeller slipstream, the gun ports in the leading edge, and the shell ejector slots in the lower surface. The ordinates of the section are given in table I. The Republic S-3 section tested has pressure-distribution characteristics similar to those of the NACA 23011 airfoil.

Surveys of the wake were made for two surface conditions of the test section with transition fixed by a thread at 5 percent chord back of the leading edge on the upper and lower surfaces. One of the surveys was made with the surfaces smooth: the other survey was made with the surfaces roughened behind the fixed transition position by an application of camouflage paint. The smooth surfaces were obtained by fairing the various surface irregularities with glazing putty, applying several coats of white lacquer-based paint, and sanding in a chordwise direction with No. 320 carborundum paper. Transition was fixed at 5 percent of the chord by means of a thread 0.036 inch (or 0.042 percent of the chord) in diameter, taped spanwise to the surface. This thread size, according to the results of reference 3, is greater than the minimum size necessary to fix transition at 5 percent of the chord for all test conditions of this investigation.

The camouflage paint was applied over the smoothed surfaces in such a manner as to produce a finish of moderate and uniform roughness. The degree of roughness was measured by means of a 40-power shop microscope (fig. 3) that had a graduated scale at the focal plane of the objective and a prism at the base for the purpose of measuring heights of small objects. The surface roughness was made up of particles of about 0.0012 inch in height and numbering roughly 40,000 per square inch. The surface of the paint between the particles was slightly wavy; the waves had an amplitude of 0.00025 inch or less.

In order to judge the degree of surface roughness of the test section relative to that present on service airplanes, the camouflage finishes of a number of service airplanes were examined with the shop microscope. The surface roughness of the service airplanes was found to consist principally of waves having an amplitude of 0.00025 or less with scattered particles of varying height (0.0005 to 0.005 in.).

Profile-drag measurements were made with a wake-survey rake (fig. 4) located 19 percent of the chord behind the trailing edge of the test section. Wake total and static pressures, free-stream impact pressure, and the position of the right aileron were measured with NACA recording instruments. The section profile-drag coefficients were determined by the integrating method of reference 4; that is, the total-pressure loss was integrated across the wake and then multiplied by factors depending on free-stream impact pressure, maximum total-pressure loss, static pressure in the wake, and flight Mach number. Wool tufts were used on the upper surface near the trailing-edge area about 2 feet on either side of the center line of the test section to determine whether any cross flow existed in the boundary layer that would invalidate the wake surveys.

The tests were made in level flight and in dives at altitudes of 12,000 and 24,000 feet and over a range of indicated airspeed from 150 to 360 miles per hour. The lift coefficients obtained in the tests ranged from 0.12 to 0.68, the Reynolds numbers ranged from 8×10^6 to 20×10^6, and the Mach numbers ranged from 0.25 to 0.73.

RESULTS AND DISCUSSION

During the tests the wool tufts on the wing surface were observed to trail straight back and thereby indicated that the wake surveys were not influenced by cross flow. The right aileron was found to be deflected from approximately 0.75° to 1.5° downward. This small variation in aileron deflection was believed to have no appreciable effect on the profile-drag coefficients measured.

The values of section profile-drag coefficient c_{d_o} for the two surface conditions are plotted against airplane lift coefficient C_L in figure 5. The corresponding values of Mach number M, Reynolds number R, and indicated airspeed V_{i_s} are plotted above the profile-drag curves. Indicated airspeed V_{i_s} is defined as the reading of an airspeed indicator of standard calibration corrected for position error of the airspeed head.

From figure 5 it may be seen that roughening the surfaces increased the section profile-drag coefficient by 0.0013, or 16 percent, at a lift coefficient of 0.16 and a Reynolds number of 17×10^6. At a lift coefficient of 0.65 and a Reynolds number of 8×10^6, the increase in section profile-drag coefficient was 0.0008, or 8 percent. Inasmuch as transition was fixed at 5 percent of the chord, these increases in section profile-drag coefficient are believed to be caused by increases in the turbulent skin-friction coefficient.

Although a comparison of the flight results of the present tests with the results of reference 1 was considered desirable, no direct comparison was possible because the correction of the results of reference 1 for movement of transition could not be determined.

The total-pressure loss across the wake for the roughened and smooth surface conditions is presented in figures 6 and 7, respectively, for several Mach numbers as a plot of $\Delta H/q_c$ against y/c, where ΔH is the loss in total pressure at position y in the wake, q_c is the free-stream impact pressure, and c is the chord of the wing section. The total-pressure loss at $y/c < 0.023$, beyond the limits of the wake-survey rake, was estimated from wake surveys made in other tests with the rake extended.

The wake profiles show that compressibility shock occurred on the upper surface, as indicated by the rapid increase in width of the wake, at a Mach number between 0.68 and 0.69 at a lift coefficient of 0.15 for the roughened surfaces and at a Mach number somewhat less than 0.71 at a lift coefficient of 0.13 for the smooth surfaces. It is estimated, however, that at a lift coefficient of 0.15 shock would occur at about the same Mach number (between 0.68 and 0.69) for the smooth surfaces as for the roughened surfaces. This estimate is based on the variation with Mach number at various lift coefficients of the total-pressure loss due to shock at position $y/c = 0.023$ in the wakes of the smooth and roughened surfaces. The formation of shock is reflected in a rapid increase in section profile-drag coefficient for the smooth and roughened surfaces in figure 5. At Mach numbers below that at which shock occurs, variations in Mach number of as much as 0.16 appear to have no appreciable effect on the section profile-drag coefficients of either the smooth or roughened surfaces.

CONCLUDING REMARKS

The results of the investigation to determine the effect of roughness on wing profile drag with transition fixed far forward indicated that surface roughness made up of particles of about 0.0012 inch in height and numbering roughly 40,000 per square inch increased the turbulent skin friction by an amount corresponding to an increase in section profile-drag coefficient of 0.0013, or 16 percent, at a lift coefficient of 0.16 and a

Reynolds number of 17×10^6. Below the Mach number at which shock occurred, variations in Mach number of as much as 0.16 appeared to have no appreciable effect on the section profile-drag coefficients of either the smooth or roughened surfaces with transition fixed.

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REFERENCES

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2. Smelt, R., and Higton, D. J.: Measurements of the Drag of Rough Painted Surfaces on a Mustang. Rep. No. Aero. 1849, R.A.E., Aug. 1943.

3. Davison, B.: Note on the Use of Threads for Ensuring Forward Transition on a Wing. B.A. Dept. Note - Wind Tunnels No. 422, R.A.E., Jan. 1940.

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TABLE I

ORDINATES OF REPUBLIC S-3 WING SECTION TESTED ON P-47D AIRPLANE

[All values given in fractions of chord; ordinates measured relative to an arbitrary chord and with inboard trailing edge of aileron in line with trailing edge of flap]

Station	Ordinate	
	Upper surface	Lower surface
0	0	0
.0125	.0192	-.0093
.025	.0310	-.0134
.05	.0444	-.0184
.075	.0535	-.0221
.10	.0604	-.0253
.15	.0674	-.0308
.20	.0706	-.0354
.25	.0711	-.0381
.30	.0705	-.0395
.35	.0685	-.0400
.40	.0656	-.0395
.45	.0627	-.0379
.50	.0589	-.0356
.60	.0485	-.0296
.70	.0354	-.0221
.80	.0230	-.0136
.90	.0105	-.0060
1.00	0	0
L.E. radius: 0.0087		

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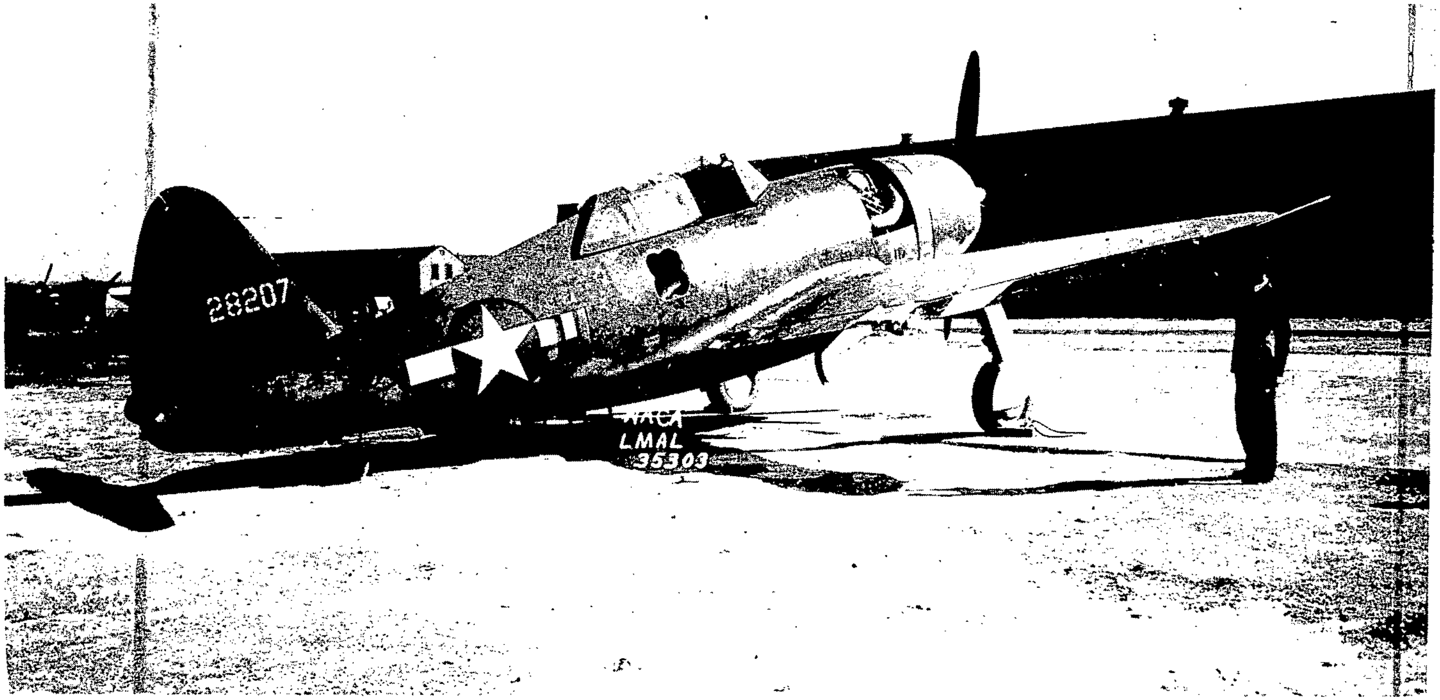

Figure 1.- P-47D airplane used for tests.

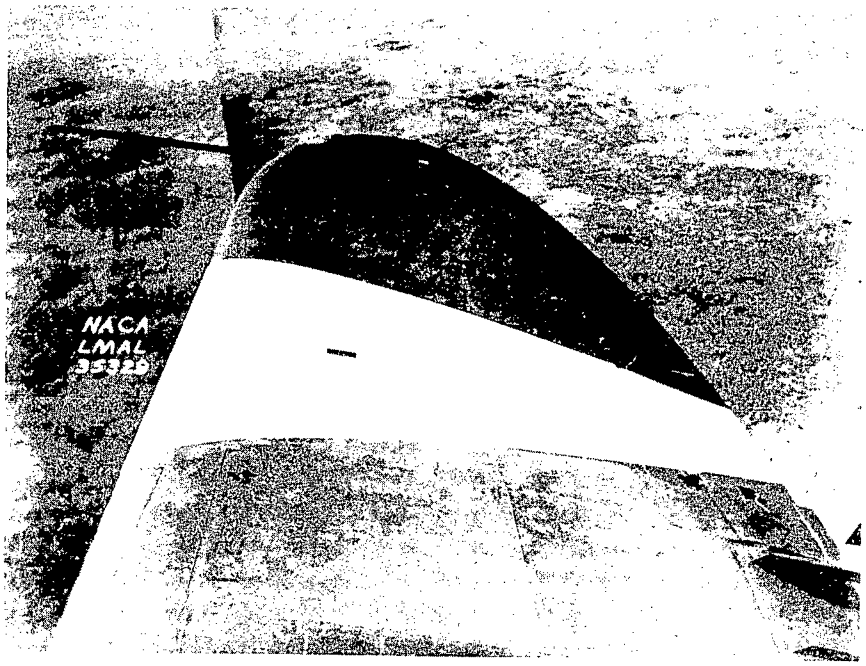

Figure 2.- Test section of wing of P-47D airplane with smooth surface.

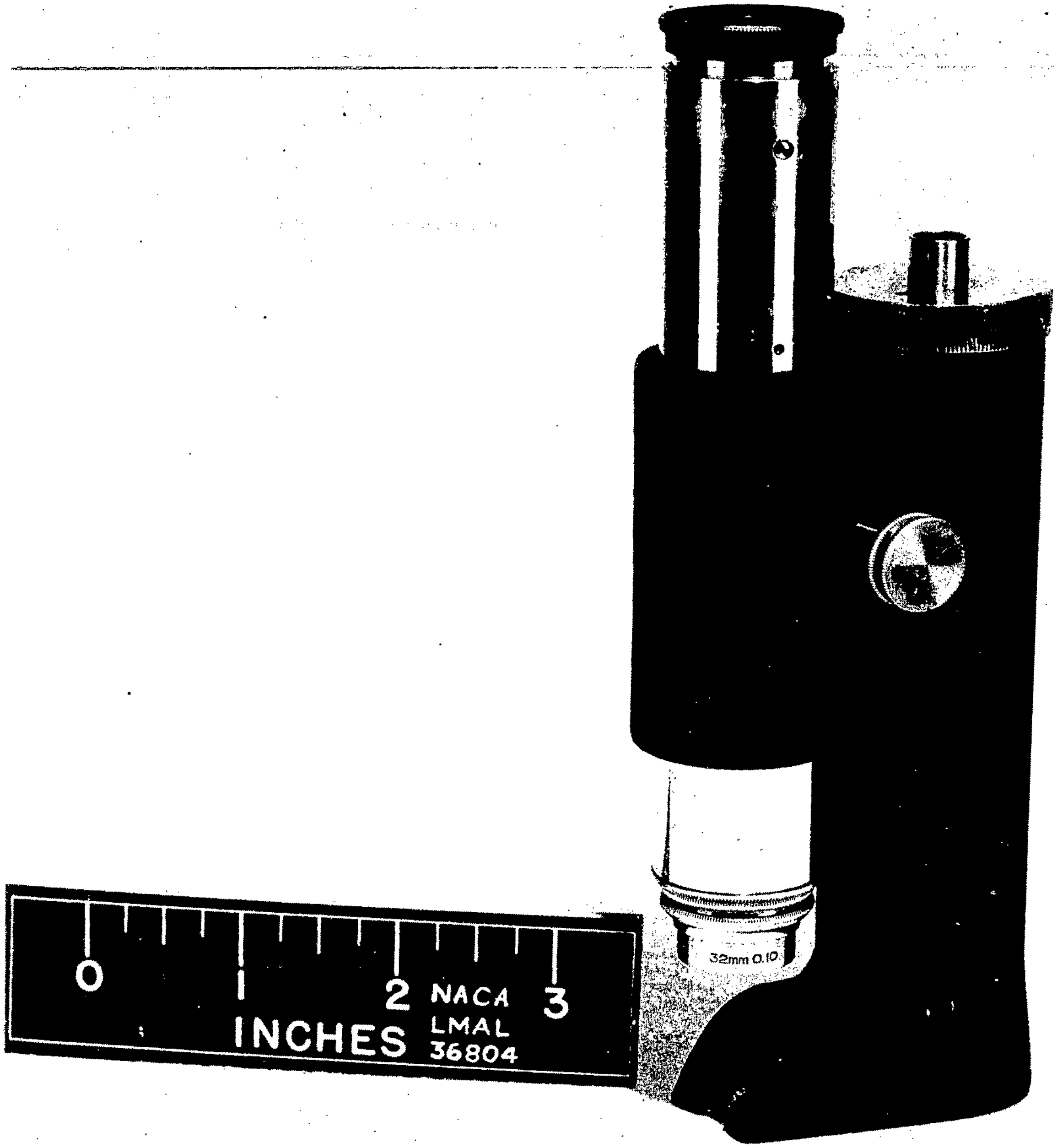

Figure 3.- Microscope with prism attached to base used in measuring surface roughness.

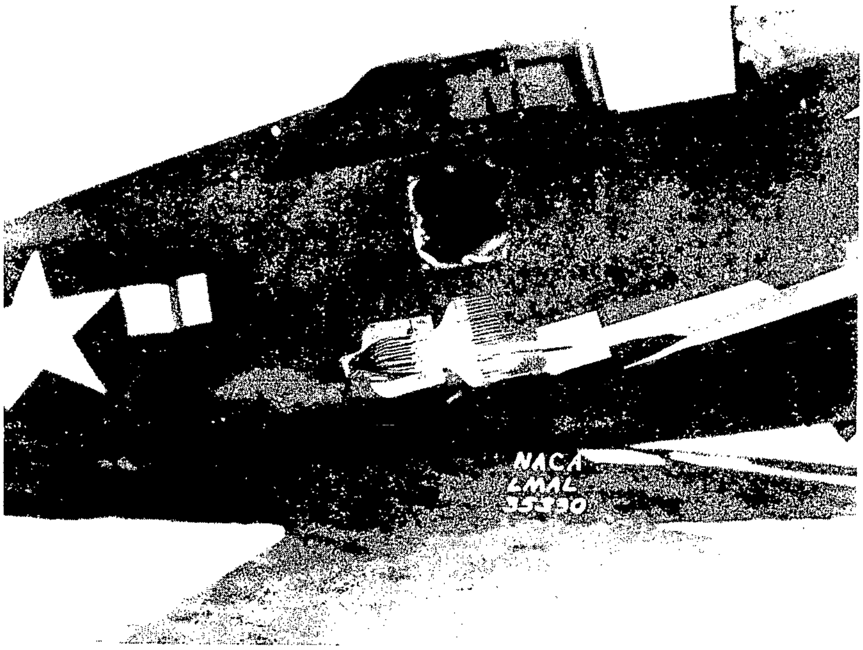

Figure 4.- Wake-survey rake installed on P-47D airplane.

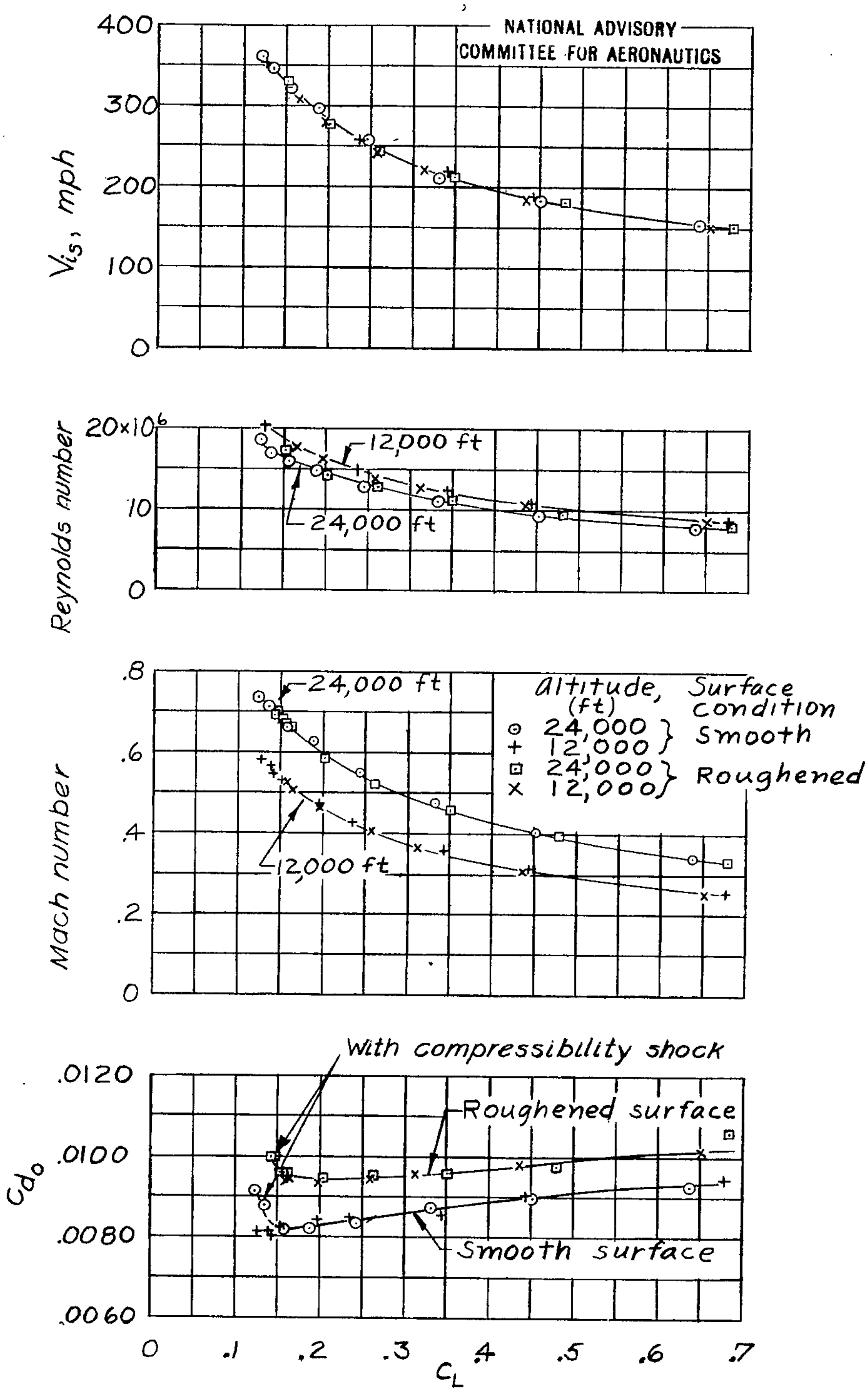

Figure 5.- Profile-drag coefficients for smooth and roughened surfaces with transition fixed at 5 percent chord. Mach number, Reynolds number and indicated airspeed are plotted above the profile-drag curves.

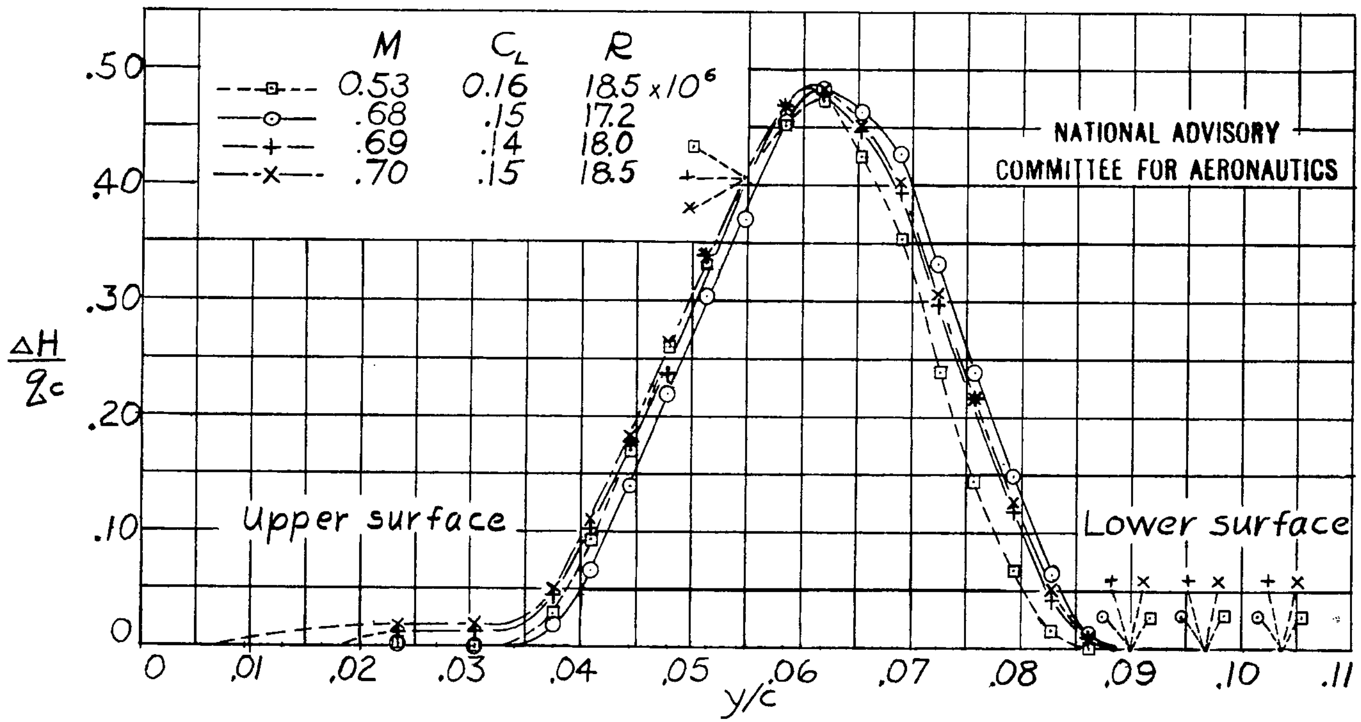

Figure 6.- Wake profiles for roughened surfaces with transition fixed at 5 percent of the chord. (y/c = 0.0235 corresponds to top tube of wake-survey rake and y/c = 0.1035 to bottom tube.)

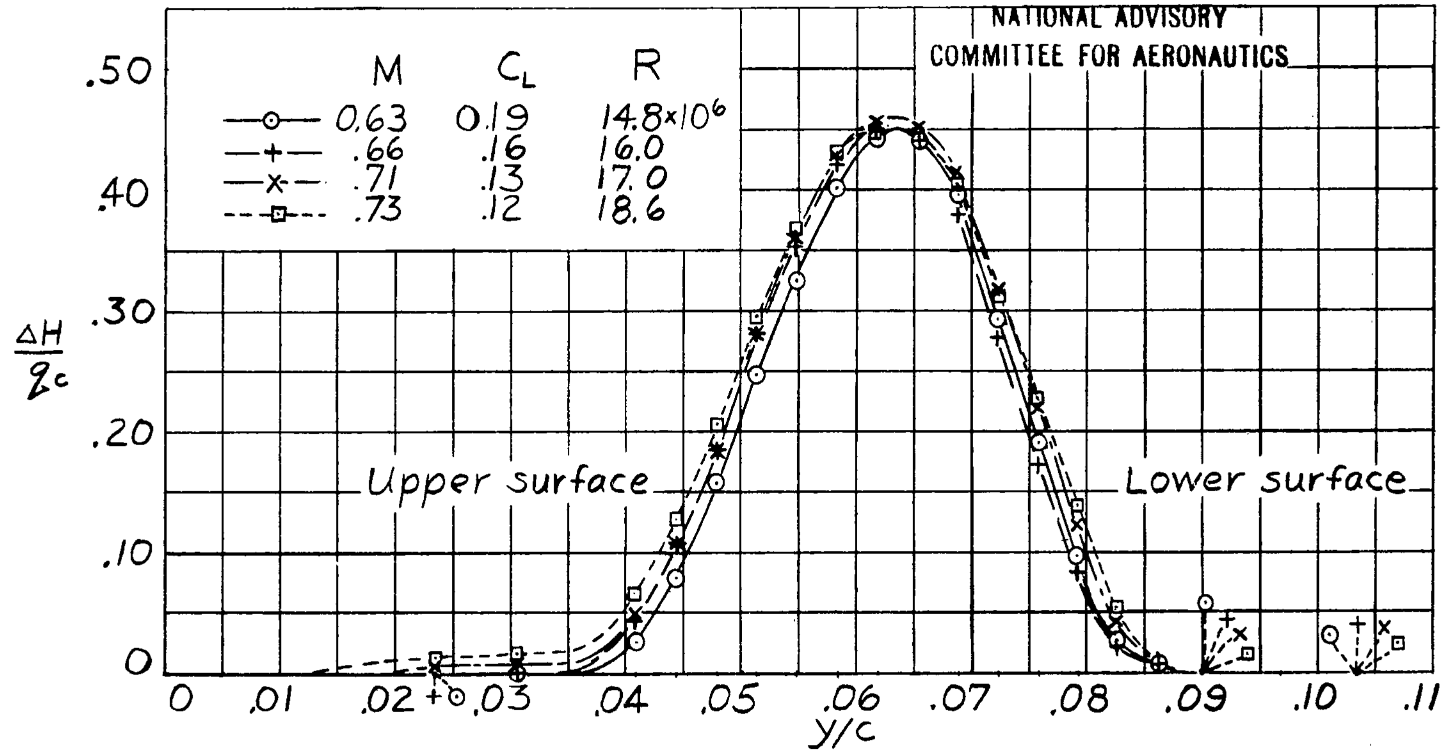

Figure 7.- Wake profiles for smooth surfaces with transition fixed at 5 percent of the chord. (y/c=0.0235 corresponds to top tube in wake-survey rake and y/c=0.1035 to bottom tube.)